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PRELIMINARY INVESTIGATION OF A LUNAR "ROLLING STONE"

By J. M. Eggleston, A. W. Patteson, J. E. Throop,
W. H. Arant, and D. L. Spooner
Manned Spacecraft Center
Houston, Texas

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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INTRODUCTION

During the analysis of Lunar Orbiter II photography at the Manned Spacecraft Center, Houston, Texas, several large boulders were noted which appeared to have moved or rolled down the interior walls of lunar craters. The boulder or "rolling stone" discussed in this paper was identified as a large, near-spherical object located at or near the bottom of a slope with a clearly defined track down that slope. This paper presents a preliminary investigation on one of the rolling stones. The boulder studied in this investigation is within the crater Sabine D at 23° 39' E longitude and 01° 20' N latitude in the southwestern area of Mare Tranquillitatis. The area, shown in figure 1, was photographed by Lunar Orbiter II as primary site six.

INVESTIGATION

A preliminary investigation was conducted to determine some of the physical characteristics of the rolling stone and the surrounding lunar terrain. The area where the boulder is located is one of the better potential lunar module landing sites. Thus, any information derived from this investigation will be helpful in the selection of lunar module landing sites.

The size and shape of the crater Sabine D were determined by measurements made on Lunar Orbiter II medium-resolution photography (fig. 2). Stereoscopic measurements were taken of the path to determine the depth of the crater. The profile constructed from the measurements is shown in figure 3. The crater was determined to be approximately 2700 meters in diameter and approximately 550 meters deep. The average slope of the crater wall along the path of the boulder is approximately 31°. The boulder came to rest at a point where the angle of the slope becomes about 13° and appears to be resting in a small crater.

The dimensions of the boulder and the track down the crater wall were measured on Lunar Orbiter II high-resolution photography. A portion of frame number 79 showing the crater Sabine D, the boulder, and the track is shown in figure 4. The measurements were taken directly from the photography and confirmed by microdensitometer measurements made with a Joyce-Loebl scanning microdensitometer. The isodensity map from the microdensitometer scans of the high-resolution negative photograph is shown in figure 5. Using the methods indicated, the boulder was determined to be approximately 9 meters in diameter. The track was found to average approximately 5 meters in width and was nearly uniform in width throughout its length. In addition, the boulder was determined to be nearly spherical in shape, a characteristic not observed on rocks nearby or on the crater rim.

The isodensity pattern of the illuminated portion of the boulder as presented in figure 5 has a greater area of density fall-off at the sunward edge of the boulder that can be explained by the combined effects of the frequency response of the photographic system and the size of the scanning aperture used on the microdensitometer. The isodensity pattern of this rock (and one other investigated thus far) shows a definite symmetry in the light reflection pattern with brightest points near the center of the illuminated area. The normally used lunar photometric function would predict that the brightest points should be at the sunward edge of the boulder with a continuing light fall-off as the shadow area is approached. (Such a pattern was observed on one of the other rolling stones.) Further consideration of the isodensity patterns of the two rocks indicates that the observed patterns can best be explained by the assumption of a convex glossy (specular) surface on the rock. The assumption of a retroreflecting or a diffuse reflectance characteristic would require a concave rock surface in the vicinity of the brightest area. It would therefore appear that the boulder analyzed for this paper is unusual in that it does not reflect light in the same way as most lunar material. One explanation for this characteristic could be the compressing or rubbing effect due to its movement down the crater wall.

The physical dimensions of the boulder and the track were used in a graphic determination of the depth of the track, and the depth was found to be approximately 0.75 meter (fig. 6). An attempt was made to analyze the shape of the track depression at several positions along the path. However, no clearly defined shape could be consistently obtained. This interpretation of slopes depends on the photometric model used in combination with the isodensitometer measurements. It is believed that the photometric function of the compressed material in the track does not follow that normally measured from the lunar surface (retroreflecting). If this difference in photometric functions is indeed the case, it might explain the difficulty in defining the shape of the track with respect to the adjoining lunar terrain.

These data were used to make some preliminary calculations to determine the approximate range of bearing strengths of the crater wall material. To simplify these calculations, the boulder and the track were considered in a static situation. If the surface area of the spherical segment of the boulder is considered as being flat, that is, the radius $\rightarrow \infty$, then the bearing strength so calculated would be conservative. However, the contact of the rolling stone with the surface was transient, and the depression made by the rolling stone is probably less than would be made by a static stone. These two effects should tend to oppose one another.

The volume of a spherical boulder 9 meters in diameter is 382 cubic meters. The mass of the boulder over a density range which would include possible rock types that might be encountered on the lunar surface is shown in figure 7. The graph covers the range of densities from 0 to 3 grams per cubic centimeter. The surface of the spherical segment of the boulder in contact with the lunar surface is 212 000 square centimeters. The ratio of the range of possible masses computed to the area results in a range of possible bearing strengths for the crater wall material. A graph of mass versus bearing strength is shown in figure 8.

The only direct measurement of the bearing strength of the lunar surface was obtained from Surveyor I and from two Russian "soft-landed" Lunik spacecraft. According to reference 1, at the impact point and under the impact conditions of Surveyor I, the lunar surface did create a maximum dynamic resistance of 4×10^5 to 7×10^5 dynes per square centimeter (6 to 10 psi). This statement is taken to mean that the dynamic bearing strength of the surface at the Surveyor I touchdown point is at least equal to or greater than 4×10^5 dynes per square centimeter. Reference 1 also states that the static bearing capacity and other soil properties that would produce such a dynamic effect have not been conclusively determined. However, in reference 2, it was stated that, if the material is homogeneous and similar to that observed at the surface to a depth of 1 foot or 30 centimeters, the preliminary analysis indicates that the soil has a static bearing capacity at the scale of the Surveyor I footpad of about 3×10^5 dynes per square centimeter or 5 pounds per square inch.

The area in which Surveyor I landed and the area in which the rolling stone is located are separated by 60° in lunar longitude. However, if the rolling stone interacted with lunar material having a bearing strength similar to that experienced by Surveyor I, then the boulder would have a uniform density between 1.3 and 2.3 grams per cubic centimeter.

Without knowing the density or mass of the lunar boulder, the bearing strength of the soil on the slopes of the crater cannot be uniquely determined. However, the following was determined:

(1) Large, cohesive, and near-spherical boulders exist on the lunar surface.

(2) At least a few lunar boulders have moved or have been moved recently enough that their tracks have not been obliterated by lunar erosional processes.

(3) One such boulder, whose reflectance properties were analyzed by microdensitometer measurements, appeared to reflect as a Lambert surface.

(4) The wall of a lunar crater (Sabine D) having a slope of about 30° appeared to be covered with a compressible material which failed under the pressure of the boulder as it moved down the slope.

Determination of the mass and density of the boulder and of the exact bearing strength of the surface on which the boulder moved will depend upon additional data. Many new and unusual features are to be found on the lunar surface, some of which will be amenable to limited analysis. The rolling stones are examples of such features. As knowledge of the lunar surface increases, it is to be expected that these isolated and limited analyses will more closely fit together.

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National Aeronautics and Space Administration
Houston, Texas, March 20, 1967
914-50-89-00-72

REFERENCES

1. Jaffe, L. D., et al.: Surveyor I Mission Report. Part II, Scientific Data and Results. Rept. 32-1-23. Jet Propulsion Lab., Sept. 10, 1966.

2. Surveyor I - A Preliminary Report. NASA SP-126, 1966.

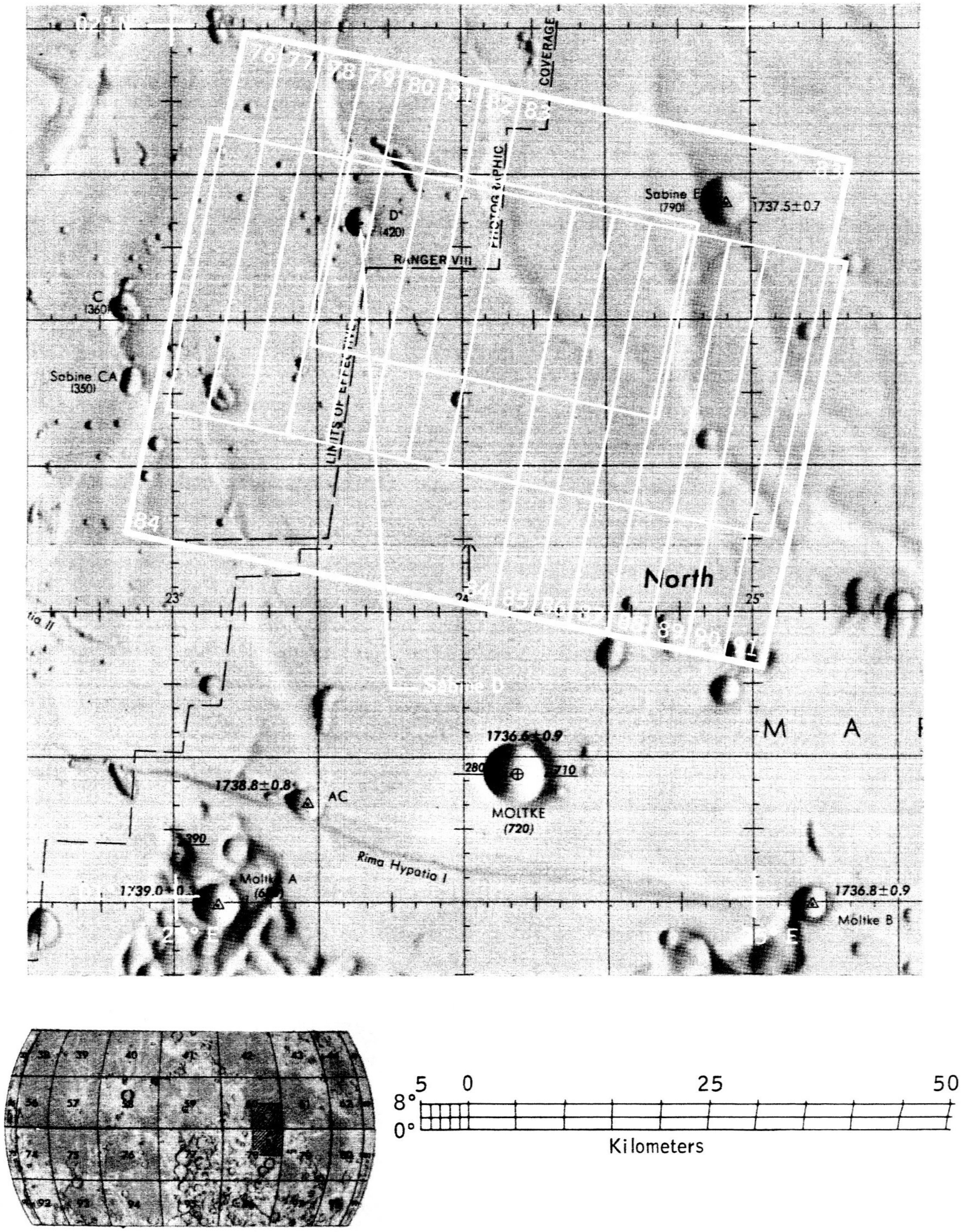

Figure 1. - Location map for Lunar Orbiter II primary site six.

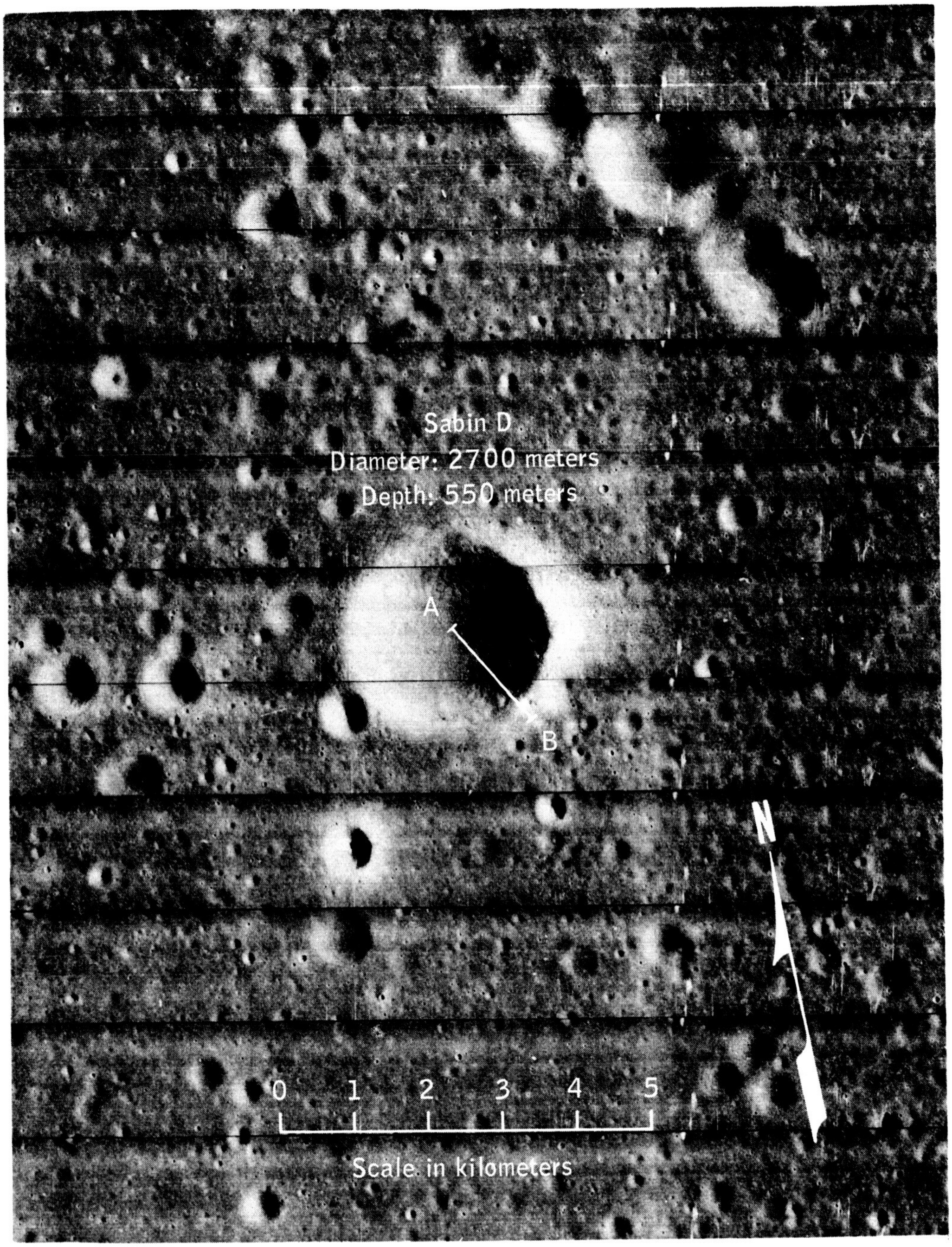

Figure 2. - Medium-resolution Lunar Orbiter II photograph showing crater Sabine D and profile line A-B.

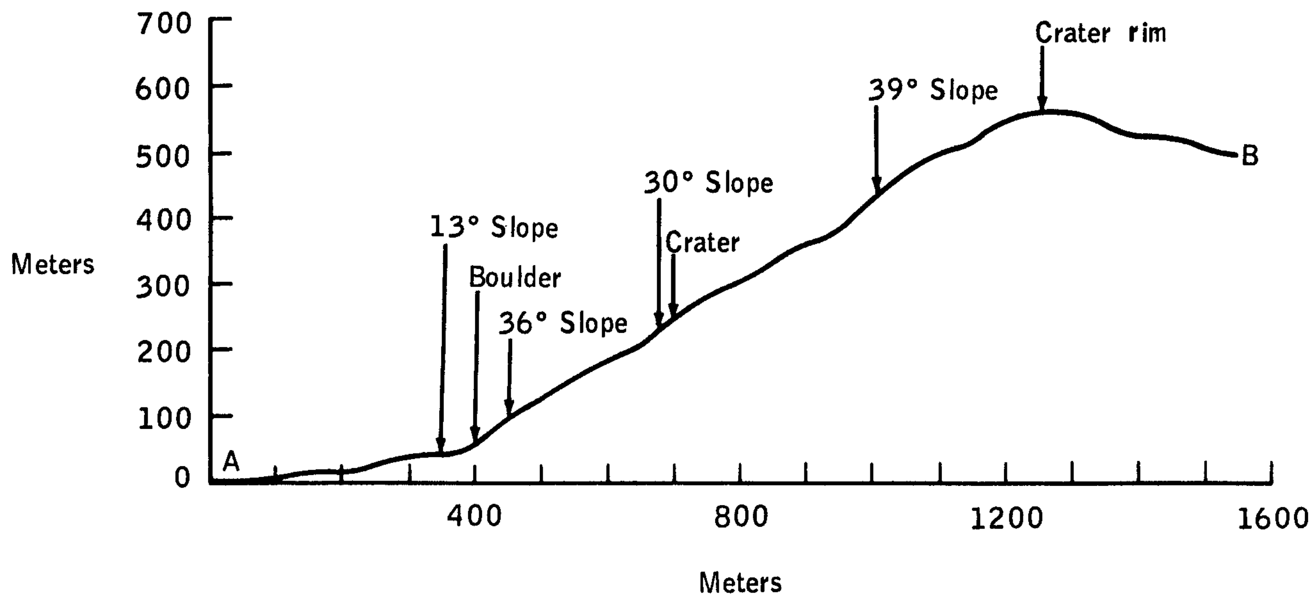

Figure 3. - Profile down wall of crater Sabine D along track of boulder.

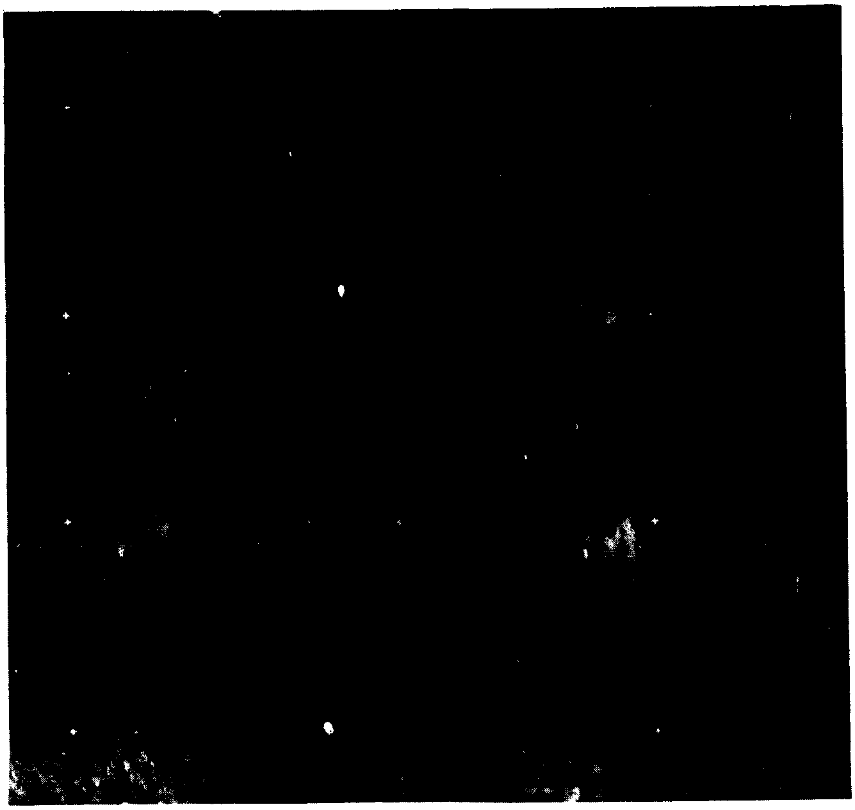

Figure 4. - Portion of photograph of crater Sabine D showing the boulder and the track.

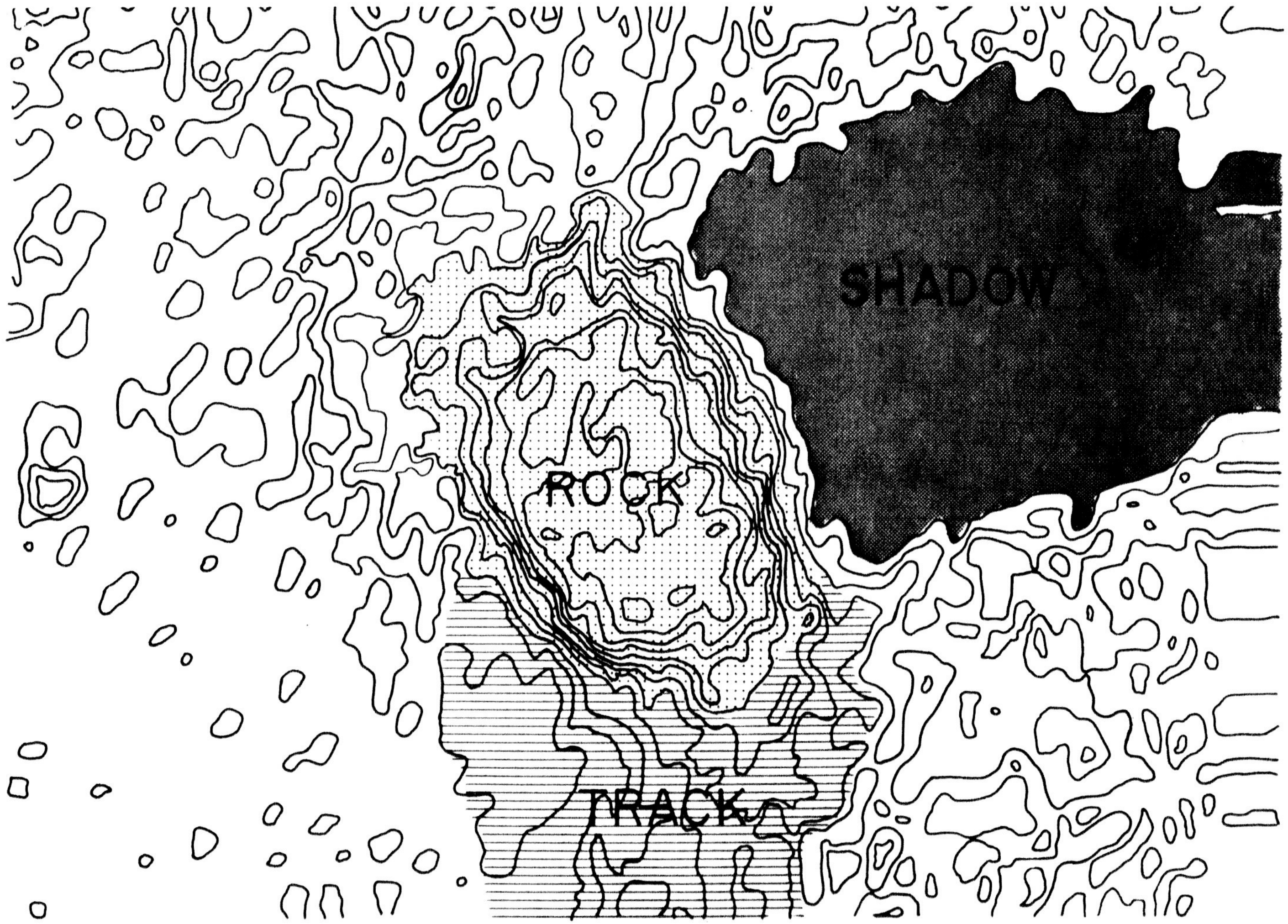

Figure 5. - Isodensity map of boulder, boulder shadow, and track from high-resolution photography.

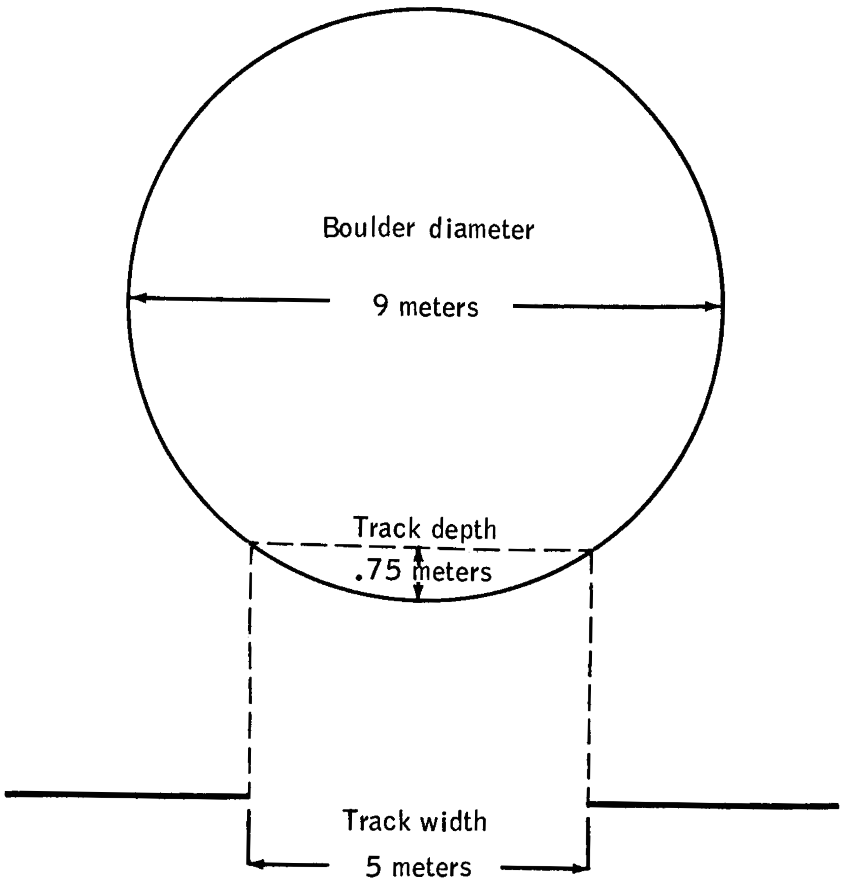

Figure 6. - Graphic determination of track depth.

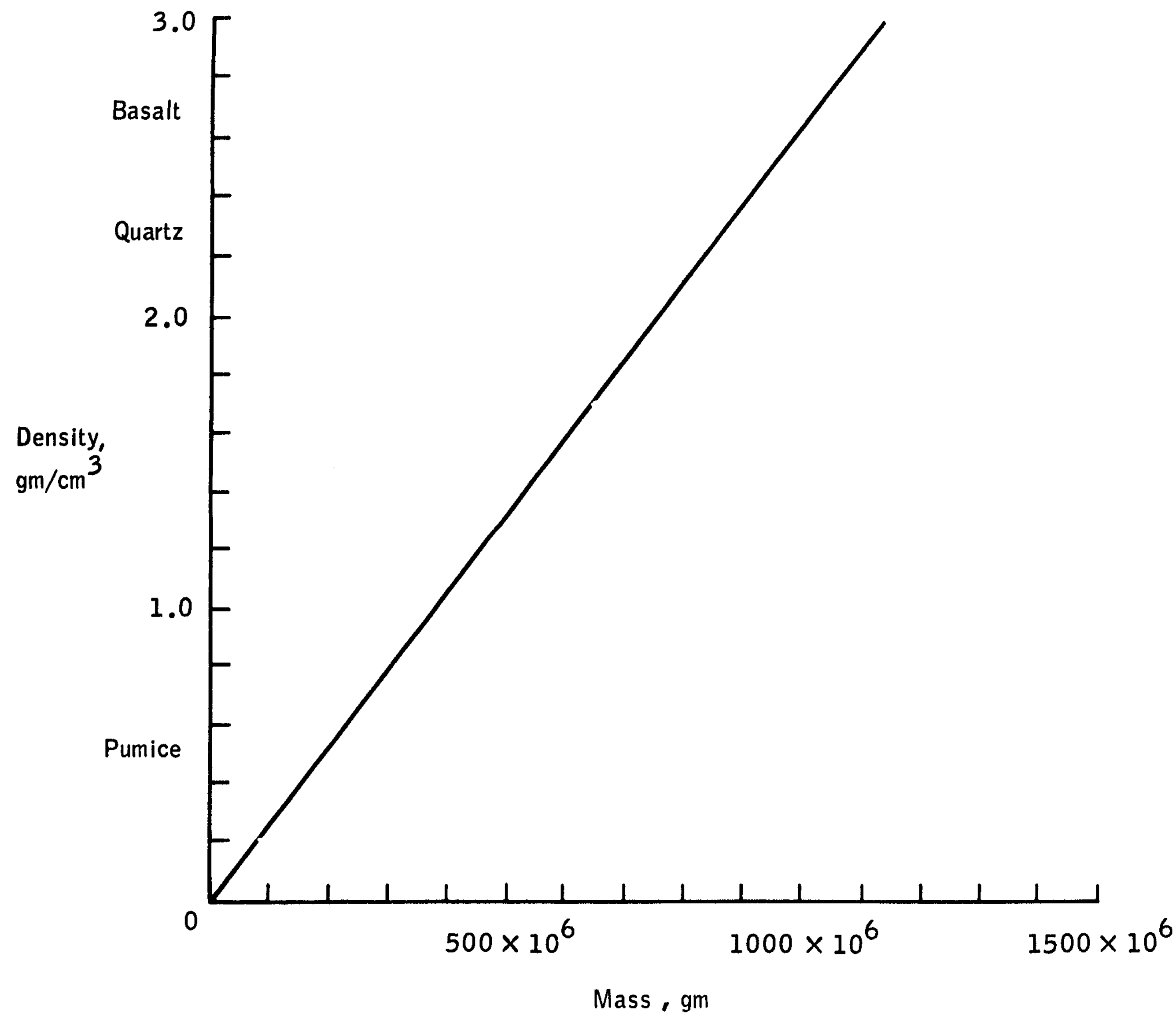

Figure 7.- Density versus mass for a range of possible lunar rock types.

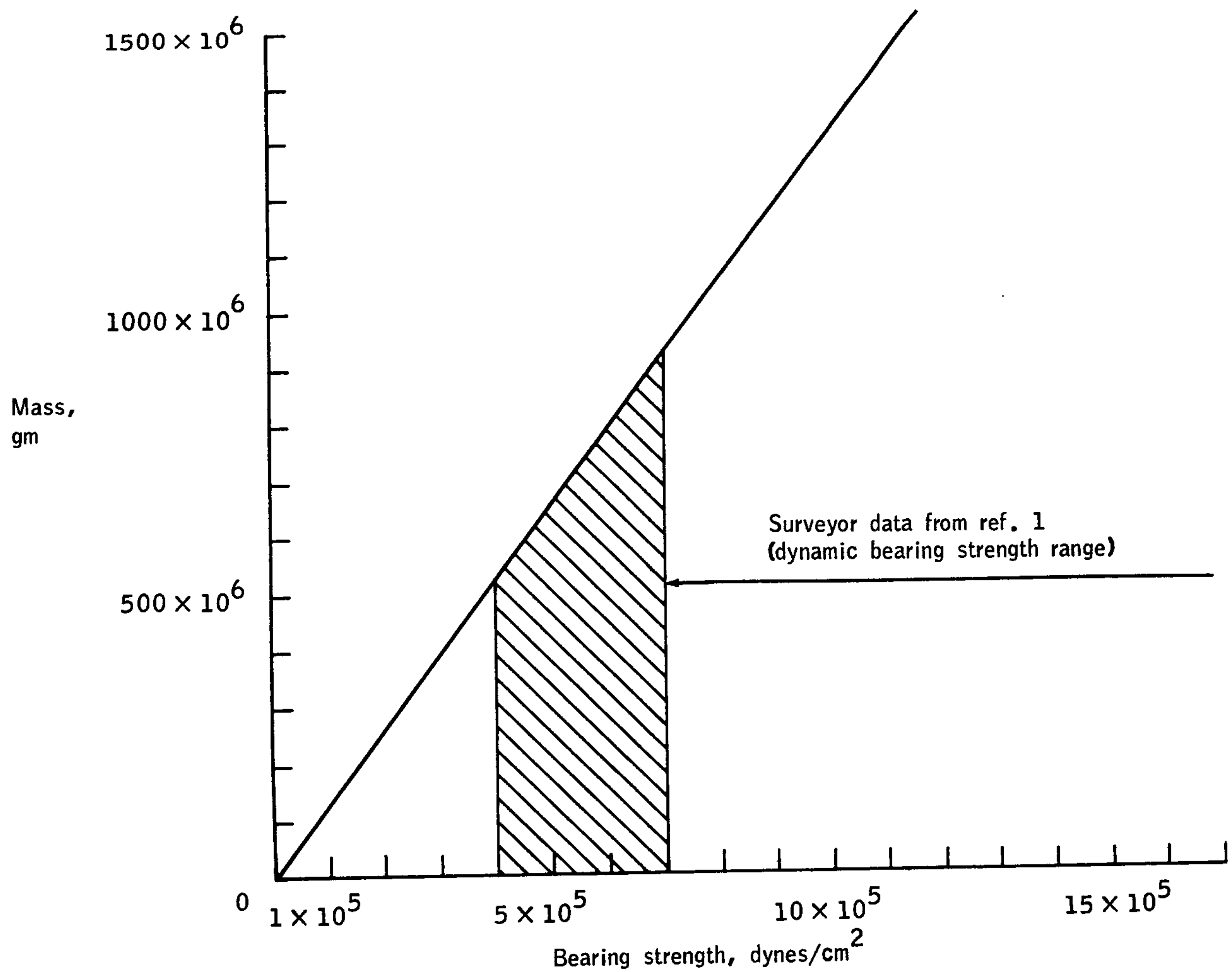

Figure 8.- Mass versus bearing strength.